

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of)	
)	
Amendment of Part 97 of the Commission's Rules)	WT Docket No. 05-235
To Implement WRC-03 Regulations)	RM-10781, RM-10782, RM-10783,
Applicable to Requirements for Operator Licenses in the Amateur Radio Service)	RM-10784, RM-10785, RM-10786,
)	RM-10787, RM-10805, RM-10806,
)	RM-10807, RM-10808, RM-10809,
)	RM-10810, RM-10811, RM-10867,
)	RM-10868, RM-10869, RM-10870

To: The Commission

REPLY TO COMMENTS, BY JAMES K. BOOMER

The following is a reply to the September 11, 2005 reply to comments submitted by Mr. Leonard H. Anderson regarding *Notice of Proposed Rule Making* (The Notice), FCC 05-143A1, WT Docket No. 05-235 released on July 19, 2005.

Summary

Five words-per-minute (5 WPM) Morse code can be decoded with 25.74dB less antenna terminal carrier input power than SSB Voice, and 11.1dB less antenna terminal carrier input than coded QPSK PSK31. This weak signal capability is a critical life and death difference in emergency communications.

Mr. Charles Young's September 13, 2005 comments submitted to the FCC on this matter, underscore the real world utility of Morse code in emergency communications and how it was the principal mode of amateur radio communications from the Katrina disaster area up until 24 hours after the hurricane hit the area.

The requirement for Morse code proficiency is mandatory in order for amateur radio to fully comply with the emergency communications provisions of Part 97, Sections 97.1, 97.3, and 97.4 of the Commission's Rules.

Discussion

Mr. Anderson's discussion of "power decibels" and "voltage decibels" is incorrect—decibels are decibels.

The equation Mr. Anderson shows:

$E_n = (4kT\Delta f R)^{1/2}$ is the basic equation for the root-mean-square (rms) thermal noise voltage in a resistance, R , in a noise bandwidth of Δf , where T is the temperature in degrees Kelvin, and k = Boltzmann's constant = 1.38×10^{-23} Joule per degree Kelvin.

The ratio of the noise voltage in two bandwidths, assuming the same R and T, is:

$$E_{n1}/E_{n2} = [(4kT\Delta f_1 R)/(4kT\Delta f_2 R)]^{1/2} = (\Delta f_1/\Delta f_2)^{1/2} \quad \text{Equation 1}$$

The ratio in decibels is:

$$(E_{n1}/E_{n2})_{dB} = 20\log_{10}(\Delta f_1/\Delta f_2)^{1/2} = 10\log_{10}(\Delta f_1/\Delta f_2) \quad \text{Equation 2}$$

Thus, the noise voltage ratio in decibels, for a 2,500 Hz bandwidth and a 500 Hz bandwidth is $10\log_{10}(2,500/500) = 6.99\text{dB}$.

The maximum power delivered by a noise source to a resistance is:

$$P_n = E_n^2/4R = kT\Delta f$$

Then, the ratio of the noise power in two bandwidths in decibels is:

$$(P_{n1}/P_{n2})_{dB} = 10\log_{10}(\Delta f_1/\Delta f_2) \quad \text{Equation 3}$$

Thus, the noise power ratio in decibels, for a 2,500 Hz bandwidth and a 500 Hz bandwidth is $10\log_{10}(2,500/500) = 6.99\text{dB}$, not 3.5dB as Mr. Anderson states.

Morse code Communications:

Signal-to-noise performance:

It is widely known among experienced Morse code operators that one can reliably receive messages at a signal-to-noise ratio (S/N) of 0dB, which corresponds to a signal-plus-noise-to-noise ratio [(S+N)/N] ratio of 3dB. One way this is accomplished in severe fading and noise environments is to send the code at a speed that can be reliably copied, including repeating characters two or more times, which substantially increases the probability of correct message receipt. With training and practice the human mind is equivalent to extremely narrow bandpass and notch filters, and can discriminate between noise bursts, interference, and the Morse character in this small S/N.

Considerable research has been done to determine Morse operators' abilities to receive the code in noise environments. One is ultimately interested in knowing the minimum signal-to-noise ratio in which one can reliably receive Morse code. One source for such information is "The Weak-Signal Capability of the Human Ear," by Ray Soifer, W2RS. This paper is available on the Internet at <http://www.n1bug.net/> (click "The Weak-Signal Capability of the Human Ear" upon entering this site).

This work spans seven years, and concludes that Morse operators can reliably receive 10 WPM Morse code at a median average signal-to-noise ratio (S/N) of -0.6dB, plus or minus 3dB (-3.6dB to +2.4dB), in a 100 Hz noise bandwidth.

I noted in my earlier comments that Morse operators can reliably receive messages at a 3dB pre-detection carrier-plus-noise to noise ratio [(C+N)/N] of 3dB. This is particularly true at a five-words-per-minute (5WPM) Morse code speed. A 3dB (C+N)/N is a 0dB carrier-to-noise ratio (C/N), which is very close to the above median number of -0.6dB. I used pre-detection C/N as a measure was because I was analyzing a system where the intermediate frequency (i.f.) bandwidth determined the post-detection bandwidth and signal-to-noise ratio (S/N)—i.e. no post-detection filtering to further narrow the receiver information bandwidth.

Today's amateur radio transceivers in wide use have selectable intermediate frequency (i.f.) bandwidths—250Hz and 500Hz are common narrow bandwidths available, and some equipments have 100Hz or less (The TEN-TEC Orion has a 100Hz i.f. bandwidth selection). These narrow i.f. bandwidths are provided for Morse code communications, and other modes that have narrow information bandwidths.

A product detector demodulates Morse code r.f. signals by mixing an internal oscillator signal with the incoming carrier signal. The output signal-to-noise ratio (S/N) in the CW mode is the same as the pre-detection C/N in the i.f. bandwidth when no post-detection filtering is present, since the product detector is simply a translator. If the signal's information bandwidth is narrower than the i.f. bandwidth, we can maximize the output S/N by adding post detection audio filtering that matches the signal's information bandwidth.

The post detection (S/N) in a receiver with a product detector is given by:

$$(S/N)_o \text{ (dB)} = (C_o/N_o)_{\text{dB}} + 10\log_{10}(B_{\text{IF}}/B_{\text{AF}}) \quad \text{Equation 4}$$

Where,

$(C_o/N_o)_{\text{dB}}$ = Pre-detection carrier-to-noise ratio (dB)

B_{IF} = Intermediate frequency bandwidth (Hz)

B_{AF} = Audio or baseband bandwidth (Hz)

Also, where, $B_{\text{IF}}/B_{\text{AF}} \geq 1$ (if B_{AF} is greater than B_{IF} , B_{IF} is the resultant post-detection bandwidth, since it is the narrowest bandwidth element).

For example, the information bandwidth of a Morse code signal sent at 5WPM by a transmitter, with keying rise and fall times of approximately 35 milliseconds, is 12Hz in a non-fading environment, and 20Hz in a fading environment (ref. ARRL Handbook CD, Version 4.0, page 12.18, Figure 12.21). Thus, we can add an electronic 20Hz audio filter at the product detector output, and improve the output (S/N) by 13.98dB. That is, from equation 4, $(S/N)_o \text{ (dB)} = 0 + 10\log_{10}(500/20) = 13.98\text{dB}$, in which case, we see that a 0dB pre-detection C/N in a 500Hz i.f. bandwidth provides an audio output S/N of 13.98dB with a 20Hz post-detection audio filter. Hence, the pre-detection C/N can be reduced to –13.98dB and the system will have an output S/N of 0dB from the 20Hz bandpass filter.

Mr. Anderson's notion that transceivers at both ends of a circuit may not be equipped for optimal Morse code reception flies in the face of his note that there are many other modes—e.g. PSK31—available. PSK31 surely requires special hardware and software. In addition, any receiver with a product detector or beat frequency oscillator (BFO) can receive Morse code r.f. signals.

Many modern amateur radio transceivers in use by radio amateurs offer AM/FM/FSK/SSB/CW (Morse code), and more modes, from HF to VHF. Audio filters are also in wide use by amateur radio operators.

Mr. Anderson mentions that Morse operators cannot distinguish Morse characters when the injection signal is removed from the demodulator. This is certainly not a revelation, since the demodulator is disabled –i.e. the oscillator injection is removed from the

detector. Similarly, SSB voice is garbled and unintelligible when we remove the oscillator injection from the product detector. So this notion mentioned by Mr. Anderson is irrelevant.

Digital Modulation

General:

With PSK, FSK, or any other digital modulation scheme, we have to define the maximum acceptable bit-error-rate (BER), from which we can determine the required pre-detection carrier-to-noise ratio. Additionally, we can lower the BER by various error detection and correction (EDAC) schemes. Some EDACs work best in burst error environments while others work best for other communications channel characteristics. In all cases, we must have a certain pre-detection C/N, resulting in a certain “raw” BER in order for the EDAC scheme to work. When the C/N falls below this value, the system falls apart, as expected—i.e. we need a certain minimum amount of signal energy for any demodulation/decoding system to work.

A system output BER of 10^{-3} (one error per thousand bits) is generally considered maximum for intelligible data communications, and a BER of 10^{-5} (one error per 100,000 bits) or less is considered very good. In practice, system implementation usually results in the need for an additional 1dB of C/N above theoretical. We refer to this as implementation loss.

We have already shown that 5WPM Morse code can be reliably decoded at a 0dB S/N. Remember, with Morse code we are not looking for maximum throughput, but rather maximum probability of connectivity.

Binary Frequency Shift Keying (BFSK):

Assuming coherent detection, a 9.5dB pre-detection C/N is required for a BER of 10^{-3} (ref. Reference Data for Radio Engineers, Sixth Edition, pages 23-25 and 23-26). Thus, allowing for implementation loss, we need a pre-detection C/N of 10.5dB.

Binary Phase Shift Keying (BPSK):

Assuming coherent detection, a 6.75dB pre-detection C/N is required for a BER of 10^{-3} (ref. Reference Data for Radio Engineers, Sixth Edition, pages 23-25 and 23-26). Thus, allowing for implementation loss, we need a pre-detection C/N of 7.75dB.

Quaternary Phase Shift Keying (QPSK):

In QPSK, we are doubling the information rate compared to BPSK, thus, we need twice the carrier input power for the same BER. Hence, a 9.75dB pre-detection C/N is required for a BER of 10^{-3} . Allowing for implementation loss, we need a pre-detection C/N of 10.75dB.

Convolutional Coding

Convolutional coding is discussed extensively in the technical literature; and a detailed treatise is beyond the scope of this paper. Suffice it to say, this coding technique is extremely effective in burst noise and fading environments, where data transmission is intermittently interrupted for significant periods of time. Maximum likelihood decoding, pioneered by Dr. A. Viterbi, is popular for this coding technique.

BPSK with hard decision maximum likelihood decoding of rate one-half, constraint length five, and coding delay of four, provides a 10^{-3} BER with a pre-detection C/N of 5.2dB. QPSK requires 8.2dB pre-detection C/N for the same BER. Thus, allowing for implementation loss, we need a pre-detection C/N of 6.2dB and 9.2dB respectively.

PSK31

Both BPSK and QPSK are in use, and coded QPSK works best in weak-signal, fading and burst noise environments. The system operates in a 31Hz information bandwidth, and is designed for communications between operators hand typing data at about 50WPM. PSK31 operates in the audio channel (after the product detector).

The convolutional coding scheme described above is used with QPSK, which requires a pre-detection S/N of 9.2dB in an information bandwidth of 31Hz. This is a -2.88 dB S/N in a 500Hz bandwidth ($9.2 + 10\log_{10}(31/500) = -2.88$ dB), and a 4.1dB S/N in a 100Hz bandwidth—e.g. in receivers with 500Hz and 100Hz i.f. bandwidths preceding the product detector.

PSK31 Versus Morse Code:

Earlier, we discussed following the product detector with a 20Hz filter in a 5WPM Morse code system. Accordingly, a C/N of -2.88 dB in a 500Hz i.f. bandwidth will produce a Morse code output S/N of 11.1dB in this 20Hz post-detection bandwidth ($-2.88 + 10\log_{10}(500/20) = 11.1$ dB). But we already determined that a trained Morse code operator can decode messages at a S/N of 0dB. Hence, we can decode 5WPM Morse messages with a pre-detection C/N of -13.98 dB in a 500Hz i.f. bandwidth, which will result in an output S/N of 0dB.

Thus, with a 500Hz i.f. bandwidth, and a 20Hz post-detection filter, 5WPM Morse code has an 11.1dB advantage over coded QPSK PSK31 [$-2.88 - (-13.98) = 11.1$ dB].

If we use a 250Hz i.f. bandwidth, which is readily available on many amateur radio transceivers, the PSK31 S/N in this bandwidth will be 0.13dB ($9.2 + 10\log_{10}(31/250) = 0.13$ dB). Note that we can also receive 5WPM Morse code reliably at this S/N with no post-detection filtering.

If we use a 100Hz i.f. bandwidth, the PSK31 S/N in this bandwidth will be 4.11dB ($9.2 + 10\log_{10}(31/100) = 4.11$ dB). Again, we can also receive 5WPM Morse code reliably at this S/N with no post-detection filtering. In fact, since we can decode 5WPM Morse code at a 0dB S/N, we need 4.11dB less receiver input carrier power than we need with coded QPSK PSK31. In other words 5WPM Morse code, with no post-detection filtering, has a 4.11dB advantage when we use a receiver i.f. bandwidth of 100Hz.

Receiver Considerations

In a receiving system, we are interested to know the required antenna terminal carrier input power to produce a desired output S/N ratio.

For a system with a product detector, we can determine this as follows:

Solving equation 4 for $(S/N)_o$ (dB), we have:

$(S/N)_o$ (dB) = (C_o/N_o) (dB) + $10\log_{10}(B_{IF}/B_{AF})$, from which,

$$(C_o/N_o)_{dB} = (S/N)_{o(dB)} - 10\log_{10}(B_{IF}/B_{AF}) \quad \text{Equation 5}$$

But,

$$C_i(dBW) = (C_o/N_o)_{dB} + 10\log_{10}kT + 10\log_{10}B_{IF} + F_{dB} \quad \text{Equation 6}$$

Where,

C_i = Carrier input in decibels (dB) with respect to one Watt (dBW)

$(C_o/N_o)_{dB}$ = Carrier to noise ratio at the demodulator input in dB

k = Boltzmann's constant = 1.38×10^{-23} Joule per degree Kelvin

T = Temperature in degrees Kelvin (Standard temperature = 290 degrees Kelvin)

B_{IF} = Pre-detection bandwidth in Hertz

F_{dB} = Receiver noise figure in decibels

Now, at 290 degrees Kelvin (standard temperature), $10\log_{10}kT = -204$; thus Equation 6 becomes:

$$C_i(dBW) = (C_o/N_o)_{dB} - 204 + 10\log_{10}B_{IF} + F_{dB} \quad \text{Equation 7}$$

Combining equation 5 and 7, we have,

$$C_i(dBW) = (S/N)_{o(dB)} - 10\log_{10}(B_{IF}/B_{AF}) - 204 + 10\log_{10}B_{IF} + F_{dB}$$

Where, $B_{IF}/B_{AF} \geq 1$ (if B_{AF} is greater than B_{IF} , B_{IF} is the resultant post-detection bandwidth, since it is the determining system, as noted earlier).

This equation further simplifies to:

$$C_i(dBW) = (S/N)_{o(dB)} - 204 + 10\log_{10}B_{AF} + F_{dB} \quad \text{Equation 8}$$

Where, $B_{IF}/B_{AF} \geq 1$, as noted above.

For example, assume a SSB voice system:

$(S/N)_{o(dB)} = 4.77\text{dB}$, corresponding to a $(S+N)/N$ of 6dB

$B_{AF} = 2,500\text{Hz}$ (we are assuming a 2,500Hz i.f. bandwidth)

$F_{dB} = 6\text{dB}$

Then, from Equation 8, we have,

$$C_i(dBW) = 4.77 - 204 + 10\log_{10}2,500 + 6 = -159.25\text{dBW}$$

Comparison of Systems:

Table 1 shows the carrier input in dBW for 5WPM Morse code, SSB voice, and PSK31 systems, as discussed above. Five words-per-minute Morse code data with receiver i.f. bandwidths of 500Hz, 250Hz and 100Hz, and no post detection filtering are also shown..

From Table 1 we see that with a 20Hz post-detection filter, 5WPM Morse code can be decoded with 25.74dB less antenna terminal carrier input than SSB Voice $(-184.99 - (-159.25) = -25.74\text{dB})$, and 11.1dB less antenna terminal carrier input than coded QPSK PSK31. This weak signal capability is a critical difference in emergency communications.

Mode	Req'd S/N (dB)	Bandwidth (Hz)	Receiver Noise Figure (dB)	Req'd Rcvr. Carrier input (dBW)	dB Difference (PSK31 reference)
5WPM Morse	0.00	20	6	-184.99	-11.10
5WPM Morse	0.00	100	6	-178.00	-4.11
5WPM Morse	0.00	250	6	-174.02	-0.13
5WPM Morse	0.00	500	6	-171.01	2.88
SSB Voice	4.77	2500	6	-159.25	14.64
Coded QPSK PSK31	9.20	31	6	-173.89	0dB (reference)

Table 1-Required Carrier Input for 5WPM Morse code, SSB Voice & Coded QPSK PSK31

Using a 250Hz i.f. bandwidth, and no post detection filtering, we can receive 5WPM Morse code messages with about the same r.f. carrier input level to the receiver's antenna terminals (actually 0.13dB less) as coded QPSK PSK31.

Using a 100Hz i.f. bandwidth, and no post detection filtering, we can receive 5WPM Morse code messages with 4.11dB less r.f. carrier input level to the receiver's antenna terminals than coded QPSK PSK31.

Furthermore, tuning in the Morse code signal is easier than tuning in the QPSK PSK31 signal.

Emergency Scenarios:

Many radio amateurs have the kinds of equipment mentioned above, and participate in emergency operations using all of the modes available, beyond those noted above at HF, VHF, and UHF.

All communications modes are important in emergencies, but clearly Morse communications systems are simple, and very effective in weak signal, fading, and noise environments.

The September 13, 2005 comments on FCC Docket 05-235, submitted to the FCC by Mr. Charles Young, AG4YO, underscore the critical need for Morse code in emergencies. He notes the large amount of Morse code amateur radio traffic coming out of the Katrina hurricane event. Mr. Young also relates that the digital infrastructure was inoperative, and at 24 hours after the event, only Morse code amateur radio emergency communications were coming out of the area. Additionally he notes the FCC's issue of a license for ship telegraphy, and includes other interesting comments on Morse code.

Clearly, Morse code is essential for emergency communications, and for amateur radio to comply with the provisions of Part 97, Sections 97.1, 97.3, and 97.4 of the Commission's Rules.

James K. Boomer Credentials

- Licensed radio amateur since February 1947 (current call is W9UJ)
- Electronics Engineer, BSEE (Major in Communications Electronics), 1954 from the University of Nebraska
- Radio Design Engineer, Collins Radio Company, Cedar Rapids, Iowa, 1954
- Jet Fighter Pilot, Instructor Pilot, and Communications Officer, U.S. Air Force, 1954-1957 (leave of absence from Collins Radio Company for military service)
- Radio and Communication Systems Design Engineer, Staff Engineer and Project Engineer (including project engineer on the 62S-1 VHF converter for the Collins HF "S-Line"), Collins Radio Company, Cedar Rapids, Iowa, 1957-1964
- Communication Systems Design Engineer and Project Engineer for National Cash Register Company, Dayton, Ohio, 1964 to 1966
- Communication Systems Staff Engineer, Design Engineer, Project Engineer, and Engineering Section Manager at Magnavox Company (now Raytheon), 1966-1974
- Communication Systems Senior Marketing Product Manager at Magnavox Company (now Raytheon), 1974-2000—Retired in 2000.